TEXTILES FOR PARACHUTES IN AIRCRAFT DECELERATION AND MISSILE RECOVERY

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Radioplane Company recently completed a Study to Establish a Parachute Research and Development Program and R & D program for Aircraft Deceleration by Parachute which should be of special interest to this Symposium.

Our experience in the application of parachutes to aircraft began in November 1939 when we placed a parachute recovery system in a 60 MPH target drone. This experience has extended through the increase in weight and speed of drone vehicles to the present 1800 pound, high subsonic turbojet Q-1 Drone. The parachute research and recovery division of our engineering department was formed in 1948 to undertake basic research and development of guided missile recovery systems for the Bureau of Aeronautics' Project Recovery. This group has since handled a variety of missile recovery and parachute development assignments.

The Study to Establish a Parachute Research and Development Program had as its objectives the compilation of all existing parachute literature; organization of the documents into bibliographies, abstracts, and reports showing the "state of the art," and recommendations for future research, based on discovery of unexplored or deficient fields of parachute knowledge. Of the more than 3000 parachute documents gathered, about 280 are listed in the Textile Materials bibliography. Of these, more than half are reports of routine tests of manufacturers' samples for conformance to specification, and nearly fifty of the remaining documents pertain to chemical treatments, notably marking fluids.

From these raw statistics, it appears on the surface that less than three per cent of the parachute research activity to date has been concerned with textiles as related to parachutes. Of course, the textile industry is so large in comparison to the parachute field, and such a small fraction of textile production is devoted to parachutes, that the parachute designer is heavily dependent on commercial research.

In connection with the R & D Program bibliography, it is important to credit the Armed Services Technical Information Agency for the compilation of a record size Demand Bibliography. This was reorganized and enlarged from other sources under the recent program to yield what may be the most complete and convenient bibliography on parachutes,

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and incidentally on parachute textiles, yet compiled.

The final report on the "state of the art" probably divulges little technical information on textiles not already familiar to most of you. But, it does confirm this: that parachute textiles are compromises between technical requirements and commercial trade practices probably to a greater degree than most other materials used in the aircraft field.

A survey of parachute textile literature indicates that parachute fabrics have been largely selected or adapted from fabrics originally designed for other applications. This is obviously an unsound approach, since parachute design requirements impose far more rigid limits on permeability, strength/weight efficiency, elongation, and other physical properties than do any other common applications of textile materials. A study of the physical properties of the individual fibers composing parachute textiles indicates that there is a considerable loss in the strength/weight ratio when the fiber is finished into a fabric or shaped textile. Some loss is inevitable, but it is apparent that no consistent effort has been made to reduce that loss and to improve the other physical properties important to parachutes until they reach the optimum for the basic fiber.

But, on the credit side, the study also confirms that research trends are in the right direction. It is hardly conceivable that all parachute textile deficiencies could be immediately corrected by an idealistic program starting with the principles of fluid mechanics and the physical chemistry of fibers. Improvements must be evolutionary, however, evolution must be guided and duplicate efforts avoided.

Immediate practical deficiencies are the outmoded specifications and the over-simplified classification of parachute materials into weight Types I, II and III. Other equally important deficiencies are the unavailability of light weight low permeability fabrics for non-solid canopies, the lack of heat resistant durable textiles, and generally the amount of compromise required to make optimum parachute design fit textile realities.

Traditionally, parachute structures have been loosely assigned to three different weight classes, defined by the weight of nylon fabric and lines employed. The three-valued system is of such limited usefulness that it no longer satisfies minimum requirements for preliminary design work.

Under our recommended R & D programs for guidance and standardization of research, the existing type system has been redefined

as a strength type system, comprising six types rather than three. Type I, for example, includes parachute materials with structural strength ranging from 25 to 50 pounds per inch. Type II ranges in strength from 50 to 100 pounds per inch. By way of comparison Type I of the existing system, using weight as its determining factor, roughly contained all fabrics in the 25 to 100 pound structural strength areas.

The strength type system lends itself more readily to quantitative and qualitative referencing of the various elements (that is webbing, tape, ribbon,etc.), which go into the making of a parachute.

When a multordinal system becomes a reality the large gaps in fabric availability will be closed and design compromises will be less drastic.

It is difficult to design parachutes in which fabric permeability is critical. Material porosity specifications are based on the standard test pressure equivalent to one half inch of water, corresponding to a low rate of descent - say 17 feet per second. But permeability is critical during inflation and opening shock, when dynamic pressure distends fabric pores in a manner not directly predictable from the specification data. Excessive porosity can prevent the parachute from inflating fully. Current and proposed research will eventually permit a full range of permeability limits to be included in fabric specifications.

The general specification for parachute textiles recommended under this program states that "the air permeability of parachute cloth and ribbon shall be measured at not less than ten different pressures including the following static pressure differentials in inches of water:

0.2, <u>0.5</u>, 1, 2, 3, 4, 5, <u>10</u>, 15 and 20."

Permeability problems have been particularly troublesome to Radioplane Company in the development of the Rotafoil parachute, which autorotates because of the natural pitch of sails formed by a single radial slot in each gore. This auto-rotation generates sail lift and centrifugal flaring of the skirt, both contributing to high drag efficiency. The development of large, light weight Rotafoils has been retarded by two significant factors affecting the critical opening velocity:

(1) Unavailability of low permeability light weight parachute fabrics.

(2) The reduction of average pressure drop across the canopy that attends increased size of the slots, aggravating the fabric permeability problem.

The relationship between mechanical and geometric porosity of parachute canopies was specifically studied, with the conclusion that the two are essentially different and not subject to simple addition in determining the total porosity of the canopy. This is easily demonstrated by comparing the critical value of total porosity of a FIST ribbon parachute with that of a solid flat canopy. The critical porosity of a FIST parachute 10 feet in diameter is given as 32 to 34 percent, while that of an equivalent solid flat canopy is 13 to 14 percent, corresponding to a critical opening velocity of 100 feet per second.

Geometrically porous canopy designs, in which the total porosity required for stability is close to the critical limit, are sensitive to variations in fabric porosity. Apparently, little has been done to provide fabrics of minimum porosity for parachutes of this type. The design of both Ring Slot and Rotafoil parachutes would be aided by the availability of standard weight cloth weaves of the lowest porosity practicable. Special coatings or treatments to reduce porosity should be investigated if necessary.

Another physical characteristic of parachute textiles, in need of further investigation, is that of energy absorption. That is, the combined strength and elasticity of the textile. This is important in determining the maximum stresses to which the fabric will be subjected under suddenly applied loads as well as the peak deceleration that will be imposed on the parachute load itself. During opening shock, parachute materials will fail in local areas where the ultimate energy absorbing capacity is exceeded. The ultimate energy absorbing capacity is indicated by the area under the stress-strain curve, and while the shape of the curve varies considerably for different materials, the product of ultimate tensile strength and ultimate elongation is a good measure of the ability of materials to absorb shock forces without failure. Some examples of this product are:

Regular Nylon,	19,750
High tenacity Nylon,	17,550
Dacron,	19,860
Glass,	7,430
Cotton,	2,820

Since the ultimate elongation of nylon is so high, its superiority would seem clearly indicated. But, in specific applications, there may be a point of diminishing returns where such extreme ultimate elongation is less important than other physical properties. This is one excellent reason for learning more about the physics of energy absorption in textiles - the fact that nylon has been rather arbitrarily credited with universal superiority while other promising materials have not been thoroughly investigated.

The materials section of the study program final report features a comparative evaluation of different textile materials by the reduction of strength/weight ratios to common units. For this purpose, Radioplane established an R_F factor defined as

$$R_F = \frac{f}{w}$$

where f = unit strength

w = unit weight

or in general units,

$$R_F = F/(F/L) = \frac{(F)}{(L)} / \frac{(F)}{(L^2)} = \frac{(F)}{(L^2)} / \frac{(F)}{(L^3)} = L$$

where F = force or weight units

L = length or dimensional units.

(1) Fibers, Filaments and Yarns

Tenacity in (grams/denier) x 3.5433 x 10^5 = R_F, inches

Tenacity in (grams/grex) x 3.9370 x 10^5 = R_F, inches

(2) Threads, Cords, Ribbons and Tapes

(Breaking strength, lb/ [lb/yd]) x

(0.00036 x 10^5) = R_F, inches

(3) Webbings

(Breaking strength, lb/ [oz/yd]) x

(0.00576 x 10^5) = R_F inches

(4) Fabrics

$$\left(\text{Breaking strength, lb. per inch width}/\left[\text{oz/sq yd}\right]\right) \times (0.20736 \times 10^5) = R_F\text{, inches}$$

Comparison of R_F values for various individual textile materials from raw fiber state through the spinning and weaving processes discloses the loss of strength due to processing and indicates fields of basic textile research required for critical parachute applications. The loss of unit strength with decrease in fabric weight or increase in yards per pound of linear materials is clearly disclosed, and the relative merits of various basic fibers are more readily compared when efficiency is compared in terms of R_F.

In the case of materials such as tapes and webbings which are loaded in one direction only, R_F losses reflect a direct loss in the efficiency with which the inherent tensile strength of the material is utilized. It is clear that most of the filling yarns serve only to bind the load bearing warp yarns together and so add to the unit weight without adding to the unit strength. Additional small increments of loss are the result of crimp, twist, and other processing variations which reduce the axial component of the tensile strength of the yarn as well as increasing the length of the yarn required per unit length of textile.

Because parachute fabrics are normally loaded by air pressure in both the warp and fill directions, the two unit strengths are generally made nearly equal. Therefore, the strength/weight ratio, based on either the warp or fill unit strength, usually will be less than 50 per cent of the strength/weight ratio of the basic textile material.

Textile testing methods were also investigated under the Parachute Study Program.

Fabric tensile strength measurements made with the "grab" method are substantially greater than those made with the "ravel-strip" method. Also the ball and diaphragm burst tests do not adequately simulate the actual process of fabric loading under applied pressure. This suggests that fabric strength and elasticity measurements would be more directly applicable to canopy stress analysis if the testing method simulated as closely as possible the type of pressure loading occurring in the canopy during opening shock. The recent development of dynamic tensile strength testing machines for textiles is indicative of the need for impact strength data which will lead to a determination of the shock loading characteristics of different parachute materials.

The basic research and development program for parachute textile materials consists of an engineering and experimental review of all materials now in use or of potential value for parachutes. This review should be aimed toward a determination of methods for producing textile end-products - products designed specifically for application to parachutes and utilizing the physical properties of the basic fibers to the best advantage. The review would determine methods of producing finished parachute textile materials to fully utilize the inherent properties of the basic fiber or filament.

It is obvious that this will require an extensive research program which must be broken down into several projects, each capable of execution by an individual contractor or agency. The results of the investigation must be interpreted in terms of economy of manufacture, with full consideration of the extremely small fraction of textile production devoted to parachutes. A Government agency or non profit institution specializing in textile research and adequately staffed or aided by competent parachute engineers, would be qualified to adjust idealized technical recommendations to economic requirements.

The final recommendations should be presented in the form of materials specifications, as well as processing data, including quality control methods for all manufacturing processes from the spinning of the yarn to the fabrication of the finished parachute assembly.

While parachute materials currently in production may be found satisfactory for certain applications, there is a superabundance of some nylon textile sizes and a scarcity of others. For example, there is an abundance of ribbons but a scarcity of cloth weights between 1.6 ounce and 4 ounces and graduated cloth weights above 7 ounces providing strengths from 300 to 1000 pounds per inch. There is also a general deficiency of specifications for nylon cloth weights up to 4 ounces having a range of porosities below 100 cubic feet per minute per square foot.

The results of a comprehensive long range program may also reveal substitute materials to serve as economic or strategic substitutes for nylon.

Other more specialized investigations were recommended under the R & D program which would be closely allied with some of the topics on the agenda of this Symposium. They include the development of more satisfactory heat resistant parachute materials through glass filament spinning techniques to improve glass textile elongation characteristics; an investigation of the weaving of metal fabrics for parachutes, and the development of treating processes for improving the heat resistance of textiles.

A study initiated by Radioplane to determine the feasibility of applying statistical techniques to parachute engineering culminated in recommending application of statistical quality control methods to parachute textiles.

Three parachute structural classes were defined in the study and are recommended in the proposed general research and development program for parachute textiles:

Class I - Requirements for structures of maximum efficiency, i. e., maximum strength/weight ratio and minimum bulk:

A. At normal temperatures.
B. At elevated temperatures.

Class II - Requirements for structures of intermediate strength/weight ratio where bulk is secondary to cost.

Class III - Requirements for structures of minimum bulk where both strength and weight are secondary to cost.

Phase II of the Aircraft Deceleration program was devoted to the development and testing of the Ring Slot parachute. This parachute was originated in its present form by WADC to effect a savings in material and fabrication costs over the otherwise quite satisfactory FIST ribbon parachute. The program objective required considerable textile investigation for exploitation. The Ring Slot parachute is a flat canopy in which the gores consist of a series of trapezoid panels with slots between. The complete canopy is thus a series of concentric fabric bands and slots, assembled by radial tapes and possibly provided with intermediate restrictor tapes from skirt to vent. Like the Rotafoil auto-rotating parachute previously described, the Ring Slot parachute, because of its high geometric porosity, is sensitive to minor variations in mechanical porosity of the fabric.

The economy of the Ring Slot parachute results both from its ease of fabrication and from the material economy of using full, half or other simple fractional bolt widths of fabric. Large scale production of this parachute might eventually justify the weaving of special widths with reinforced selvedges to simplify fabrication of the parachute and further reduce manufacturing costs. However, it was the objective of this program to consider only parachutes which could be fabricated from standard bolt widths without scrap.

In Radioplane's taxi tests of the Ring Slot parachute, the design was found to be highly competitive with the FIST ribbon for aircraft deceleration. But, like its predecessor, the relationship between stability and porosity is critical and has required much development. While a variety of FIST ribbon parachutes may be constructed from a standard ribbon, the design of a Ring Slot parachute for its much wider ring width is obviously much less flexible if whole, or simple fractional, cloth bolt widths are to be used. It was found feasible to design satisfactory deceleration chutes under this limitation but economical production of high performance Ring Slot parachutes would obviously be facilitated if textile manufacturers could supply a variety of selvedge materials in narrower widths. In making a suggestion of this sort, the parachute engineer is obviously limited by unfamiliarity with some of the textile manufacturers' production and economic problems. Closer control of fabric permeability would also facilitate more precise design of high performance Ring Slot parachutes. As a result of new requirements, the development of a new parachute is an excellent stimulus to closer cooperation between the parachute and textile engineering fields.

Radioplane Company's considerable experience in guided missile recovery has probably influenced the parachute study program and has led to the emphasis placed on some of the problems just discussed. The extremes of speed and the limitations of space available for guided missile deceleration and lowering parachutes expose the shortcomings of our knowledge. Conversely, the design factors applied to parachutes for personnel and cargo use cover up these shortcomings, so it is only recently that many of them have been disclosed to the parachute designer and textile engineer.

As a using agency, Radioplane is in a position to extend comments and criticisms, with regard to parachute textiles of which we hope some are constructive and not too obvious.

(1) The basic spinning and weaving techniques naturally have their ancestry in the garment trade rather than in parachute engineering. They recently have been opened to review and criticism, but little evidence has been found of any attempt, even academic, to design a parachute textile from scratch. This is a serious suggestion brought down to earth from the ivory tower. Many parachute engineers would be satisfied and perhaps even silenced on the subject if a highly qualified textile engineer would present the hypothetical design and development of a parachute fabric for a specific application, starting with the chemistry of the synthetic and carrying through the spinning, twisting, weaving, calendering, or whatever ideal treatment the cloth should receive prior to fabrication into a specified parachute. Incidentally, do the textile engineers themselves have some suggestions as to fabrication practices?

(2) The selection of fabrics is poor. There is a scarcity of fabrics in certain weight and permeability ranges, and a superabundance in others.

While not entirely consistent with the discussion thus far, the conclusion to the textile materials section of the parachute study final report will sum up many of the foregoing considerations and offer a general picture of the parachute textile situation as it appears after a survey of the literature on the subject:

A wide variety of natural and synthetic textile materials has been developed, many of which are suitable for parachute fabrication. Evaluation of the physical properties of the basic filaments, fibers, yarns, and finished textiles reveals considerable variation resulting from manufacturing tolerances. Also, between the basic material and the finished product a definite change occurs in certain characteristics. These changes may be attributed to the results of the spinning and weaving operations and to other finishing processes. The physical properties of the finished textile are not the same as those of the basic fibers and filaments and, though similar in nature, are necessarily more complex and variable. In general, the large number of textile characteristics that are of importance to parachute design and fabrication have not been adequately defined or determined in a form suitable for selective evaluation.

Comparative evaluation of different materials and textile forms was aided by the reduction of strength/weight ratios to common units. This device also revealed the efficiency with which the inherent tensile strength of the material was being utilized in the finished textile.Fabrics, for example, show a decrease in warp or fill strength/weight ratio ranging from 39% to 83%. This loss in efficiency may be attributed to such factors as the ratio of working material to non-working material yarn twist, the extra material absorbed by crimp, and the weakening effects of crimp and other processing factors.

Since the strength of textile in either the warp or fill directions is determined mainly by the number of filaments in the yarn and the number of yarns per unit width, a large number of different combinations will give the same resultant strength. This variable, in combination with different weave patterns and yarn twists, makes it possible to produce fabrics of the same strength/weight ratio which differ greatly in air permeability, a matter of considerable importance to parachute operation and design. Because the yarn weight and twist and the weave pattern, unlike rigid structures, are subject to local variations, the air permeability of fabric is not uniformly distributed. For this reason the measured porosity of cloth samples from the same bolt shows marked departures from the average,

depending somewhat upon the size of the area sampled and the differential pressure applied to it. Local variations in porosity are important to parachute operation only if they are large enough to affect the average value and distribution of porosity over the entire canopy. However, there is a general need for closer control of fabric porosity, and this requires the production of firmer, more uniform weaves. Suitable revisions of parachute cloth specifications in regard to yarn denier, twist, and ply as well as pick and fill counts and weave patterns,may prove to be productive.

In order to draw some conclusion as to the relative merits of the different materials studied for parachute fabrication, it is necessary to define the physical properties required. These differ considerably for different parachute types and applications, and it is convenient to designate three main structural classes as determined by the cost of the textile materials:

Class I - Requirements for structures of maximum efficiency, i.e., maximum strength/weight ratio and minimum bulk.

A. At normal temperatures.
B. At elevated temperatures.

Class II - Requirements for structures of intermediate strength/weight ratio where bulk is secondary to cost.

Class III - Requirements for structures of minimum bulk where both strength and weight are secondary to cost.

The physical properties of textiles that are of significance to parachute performance and design include:

(a) Strength and strength/weight ratio
(b) Elasticity and ultimate elongation
(c) Resilience and flexibility
(d) Air permeability
(e) Unit weight or average density
(f) Durability

Strength and elasticity together define the energy absorbing characteristics of the material. This is important in determining the maximum stresses to which the fabric will be subjected under a suddenly applied load, such as parachute opening shock. During opening shock, parachute materials will fail in local areas where the ultimate energy absorbing capacity is exceeded.

The strength/weight ratio of the material largely determines the strength/weight ratio of the finished parachute, and so may be used as a criterion of structural efficiency. The flexibility and unit weight of the material determine the average packing densities. Resilience will influence the ability of the material to recover its normal state after being tightly compressed in a parachute pack. The toughness rating is important in determining the durability of finished textiles, along with other properties such as resistance to moisture, fungus, and chemical action.

With due allowance for cost and availability, which ultimately determine the feasibility of employing specific textiles for parachute fabrication, the following natural and synthetic materials are among the best now known for the different classes of construction.

Class	Material
IA	Nylon, Dacron
IB	Fiberglass
II	Rayon, Fortisan, Cotton
III	Paper, Jute

Class IB requires high strength/weight ratios at elevated temperatures, and Fiberglass appears to be the only qualifying textile available today. Because of its poor energy absorbing characteristics, Fiberglass is not well adapted for parachute requirements, although some improvement can be effected by special spinning and weaving techniques. In view of the growing demand for parachutes, capable of surviving aerodynamic heating at high velocities and of operating in the hot wake of jets and rockets, an investigation of other possible high temperature textile materials, such as silicone compounds, spun steel, and other metals, may be justified.